Tillage, cropping sequence, and nitrogen fertilization effects on dryland soil carbon sequestration and carbon dioxide emission

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1. Abstract

Novel soil and crop management practices are needed to increase soil C storage and reduce greenhouse gas emission under dryland cropping system in the northern Great Plains, USA. The study compared no-tilled continuous cropping with conventional-tilled crop-fallow with or without N fertilization on dryland soil C storage and CO_2 emission. Main treatments were no-tilled continuous malt barley (NTCB), no-tilled malt barley-pea (NTB-P), no-tilled malt barley-fallow (NTB-F), and conventional-tilled malt barley-fallow (CTB-F), with split-plot application of two N fertilization rates (0 and 80 kg N ha^{-1}). Total soil C concentration at the 0-120 cm depth was not influenced by treatments and decreased from 14.4 g kg^{-1} at 0-5 cm to 12.5 g kg^{-1} at 10-30 cm but increased to 33.7 g kg^{-1}at 60-90 cm because of presence of high inorganic C. As a result, total C content varied from 9.1 Mg ha^{-1} at 5-10 cm to 149.7 Mg ha^{-1} at 60 to 90 cm. The CO_2 flux increased from 13 kg CO_2-C ha^{-1} d^{-1} on 125 DOY (Day of the year) to 173 kg CO_2-C ha^{-1} d^{-1} on 237 DOY in 2006, as soil temperature and water content increased. The CO_2 flux was greater in NTCB than in NTB-P and NTB-F on 179 and 221 DOY, greater with NTCB, NTB-P, and NTB-F than with CTB-F in 228 DOY, and greater with NTB-P than with NTCB, NTB-F, and CTB-F on 237 DOY. Averaged across measurement dates, CO_2 flux was greater in NTCB with 80 kg N ha^{-1} than in NTCB with 0 kg N ha^{-1}, NTB-P with 80 kg N ha^{-1}, and NTB-F with 0 kg N ha^{-1}. Similarly, CO_2 flux was greater with NTCB, NTB-P, and CTB-F than with NTB-F, and greater with 80 than with 0 kg N ha^{-1}. Although management practices did not influence soil total C within a 2-yr period, continuous cropping with N fertilization increased CO_2 emission compared with crop-fallow without N.

2. Introduction

Agricultural practices can contribute about 25% of total anthropogenic CO_2 emissions, a greenhouse gas responsible for global warming (Duxbury, 1994). Soil can act both as source and sink of atmospheric CO_2. While practices, such as tillage, can increase CO_2 emission from soil by disrupting soil aggregates, incorporating plant residue, and oxidizing soil organic C (Jastrow et al., 1996), no-tillage practices and increased cropping intensity can increase soil C storage (Lal et al., 1995). Cropping can increase CO_2 emission compared with fallow by increasing respiration by plant roots and by affecting on the quality and quantity of crop residue returned to the soil (Sainju et al., 2008). The effect of N fertilization on soil CO_2 emission and C storage had been variable (Sainju et al., 2008). Since conventional tillage with crop-fallow systems have reduced 30-50% of soil organic matter in the last 50 to 100 yr in the northern Great Plains, USA (Haas et al., 1957), improved management practices are needed to increase soil C storage and reduce CO_2 emission in the dryland cropping system.

3. Materials and methods

Soil CO_2 emission, temperature, and volumetric water content were measured between 9 A.M. and 12 A.M. of the day at the same place of the plot from May to October, 2006 with an Environmental Gas Monitor chamber attached to a data logger (Haverhill, Massachusetts, USA). Main treatments established in 2005 were no-tilled continuous malt barley (NTCB), no-tilled malt barley-pea (NTB-P), no-tilled malt barley-fallow (NTB-F), and conventional-tilled malt barley-fallow (CTB-F), with split-plot application of four N fertilization rates (0, 40, 80, and 120 kg N ha^{-1}) to malt barley in the second phase of the rotation in 2006. Nitrogen fertilizer was also applied to malt barley at 80 kg N ha^{-1} in the first phase of NTCB but pea and fallow phases did not receive N fertilizer. The P and K fertilizers were applied to malt barley and pea at 29 kg P ha^{-1} and 27 kg K ha^{-1}, respectively. Recommended doses of herbicides and pesticides were applied to malt barley and pea and herbicides and/or tillage were applied to fallow plots to control weeds. Total C concentration in soil samples collected at the 0-120 cm depth from five places in the plot after crop harvest in October 2005 and 2006 was determined by using a dry combustion C and N analyzer (LECO, St. Joseph, Michigan, USA). Data were statistically analyzed using Repeated Measure of Analysis in the MIXED procedure of SAS (Littell et al., 1996).

4. Results and discussion

Soil CO_2 flux increased from 13 to 173 kg CO_2-C ha^{-1} d^{-1} from May to August, 2006 and then declined to 3 kg CO_2-C ha^{-1} d^{-1} in October, as soil temperature and water content increased and decreased (Fig. 1). The CO_2 flux was greater in NTCB than in NTB-P and NTB-F on 179 and 221 DOY, greater in NTCB, NTB-P, and NTB-F than in CTB-F on 228 DOY, and greater in NTB-P than in NTCB, NTB-F, and CTB-F on 237 DOY (Fig. 1A). Soil temperature was greater in NTCB than in NTB-F and CTB-F on 179 DOY but was greater on CTB-F than in NTCB and NTB-P on 200 DOY (Fig. 1B). Soil water content was greater in NTB-F than in NTCB, NTB-P, and CTB-F on 158 DOY but was greater in CTB-F on 215 DOY and in NTB-P on 237 DOY than with other treatments (Fig. 1C). Soil water content was also greater in NTB-P and CTB-F than in NTCB and NTB-F on 249 and 264 DOY. Averaged across measurement dates, CO_2 flux was greater in NTCB with 80 kg N ha^{-1} than in NTCB and NTB-F with 0 kg N ha^{-1} and in NTB-P with 80 kg N ha^{-1} (Table 1). Soil temperature was greater in CTB-F with 0 kg N ha^{-1} than in NTB-P with 80 kg N ha^{-1}. Soil water content was greater in NTB-P with 0 kg N ha^{-1} than in NTCB, NTB-F and CTB-F with 80 kg N ha^{-1}. Averaged across measurement dates and N rates, CO_2 flux was greater in NTCB, NTB-P, and CTB-F than in NTB-F. Averaged across measurement dates and tillage and cropping sequences, CO_2 flux was greater with 80 than with 0 kg N ha^{-1} but soil temperature and water content were greater with 0 than with 80 kg N ha^{-1}. Soil total C concentration and content in 2005 and 2006 were not influenced by treatments, but concentration varied with soil depth (Table 2).

Variations in CO_2 flux with measurement dates were probably a result of changes in soil temperature and water content, as they are related (Sainju et al., 2008). The increased CO_2 flux in NTCB on 179 and 221 DOY (Fig. 1A) was probably a result of increased root respiration, since plant density and aboveground biomass were greater with this treatment (unpublished data). Similarly, increased CO_2 flux in NTCB with 80 kg N ha^{-1} (Table 1) was probably due to increased crop yield and root respiration due to N fertilization. In contrast, increased CO_2 flux in NTB-P on 237 DOY was probably due to increased decomposition of crop residue after harvest, as soil water content increased (Fig. 1C) due to increased rainfall (Fig. 1D). The lower CO_2 flux in NTB-F than in other tillage and cropping sequence (Table 1) was probably due to reduced crop residue input, followed by its lower rate of decomposition. Nitrogen fertilization increased CO_2 flux compared with no N fertilization, probably a result of increased crop residue production and root respiration, a result similar to that reported by Sainju et al. (2008). Nitrogen fertilization, however, decreased soil temperature and water content, probably a result of shading effect and more soil water removal due to greater plant growth than no N fertilization. Soil total C concentration and content did not change with treatments, since it changes slowly with time (Lal et al., 1995; Sainju et al., 2008). Because of large soil inorganic C concentration, total C concentration and content, however, increased with depth (Sainju et al., 2007).

5. Acknowledgement

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6. References

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Table 1 Effects of tillage, cropping sequence, and N fertilization on soil surface CO_2 flux, temperature, and water content averaged across measurement dates in 2006 at the study site, 8 km north of Sidney, Montana, USA

Tillage and cropping sequence[a]	N fertilization rate (kg N ha^{-1})	Soil surface CO_2 flux (kg CO_2-C ha^{-1} d^{-1})	Soil temperature (°C)	Soil water content (m^3 m^{-3})
NTCB	0	42.6	19.2	0.185
	80	52.0	19.3	0.180
NTB-P	0	48.0	19.3	0.194
	80	43.2	18.7	0.183
NTB-F	0	37.9	19.3	0.183
	80	43.7	19.2	0.177
CTB-F	0	43.7	19.5	0.184
	80	48.8	19.1	0.180
LSD (0.05)[b]		8.3	0.7	0.011
Means				
NTCB		47.3a[c]	19.2a	0.183a
NTB-P		45.6a	19.2a	0.189a
NTB-F		40.8b	19.0a	0.180a
CTB-F		46.2a	19.3a	0.182a
	0	43.1b	19.3a	0.187a
	80	46.9a	19.0b	0.180b

[a] Tillage and cropping sequence are CTB-F, conventional-tilled malt barley-fallow; NTB-F, no-tilled malt barley-fallow; NTB-P, no-tilled malt barley-pea, and NTCB, no-tilled continuous malt barley.

[b] Least significant difference between treatments at $P = 0.05$.

[c] Numbers followed by different letters within a column of a set are significantly different at $P = 0.05$ by the least square means test.

Table 2 Soil total C concentration and content at the 0-120 cm depth averaged across treatments in 2005 and 2006 at the study site, 8 km north of Sidney, Montana, USA

	Total C concentration (g kg^{-1})		Total C content (Mg ha^{-1})	
Soil depth (cm)	2005	2006	2005	2006
0-5	14.5c[a]	14.4c	9.5	9.5
5-10	12.8d	12.5d	9.3	9.1
10-30	12.5d	14.7c	34.9	40.7
30-60	32.5a	31.9a	141.3	139.0
60-90	32.1a	33.7a	143.6	149.7
90-120	30.0	28.2	123.5	116.1

[a] Numbers followed by different letters within a column are significantly different at $P = 0.05$ by the least square means test.

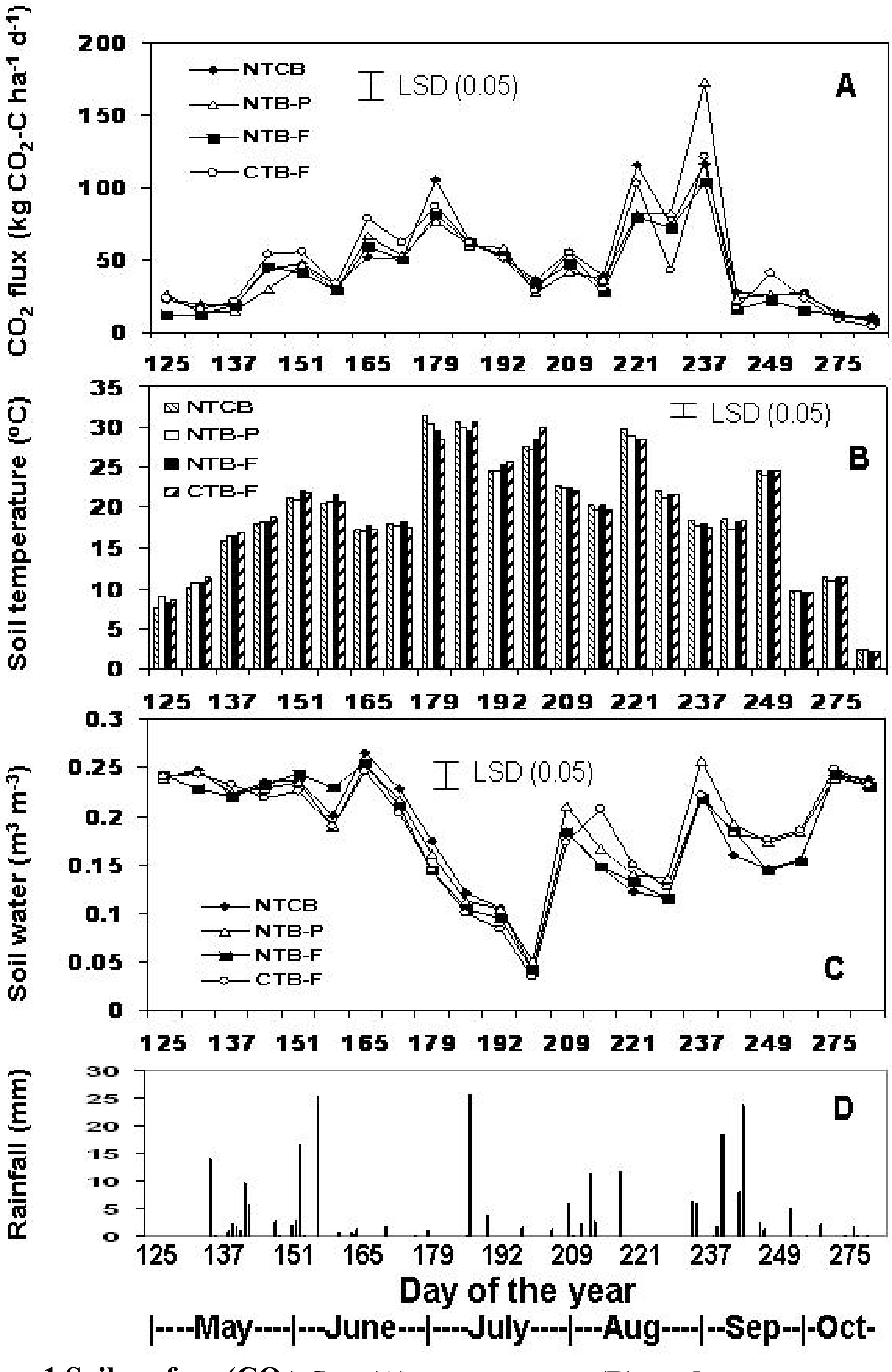

Figure 1 Soil surface (CO_2) flux (A), temperature (B), and water content (C) as influenced by tillage and cropping sequence and rainfall (D) from May to October 2005-2006 at the study site, 11 km north of Sidney, Montana, USA. CTB-F represents conventional-tilled malt barley-fallow; NTB-F, no-tilled malt barley-fallow; NTCB, no-tilled continuous malt barley; and NTB-P, no-tilled barley-pea